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A State of the Environment Report

SOE Report No. 92-2

A State of the Environment Report

The State of Canada's Climate: Temperature Change In Canada 1895-1991

D.W. Gullett and W.R. Skinner

Atmospheric Environment Service
Environment Canada

Également disponible en français sous le titre *L'état du climat au Canada : les variations de la température au Canada 1895-1991*

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Preface

The Government of Canada underscored its commitment "to secure for current and future generations a safe and healthy environment and a sound and prosperous economy" under Canada's Green Plan. It is recognized that access to credible, balanced information is the foundation for building increased environmental awareness and improved decision-making, and ultimately sustaining our natural, economic and cultural heritage.

Canada, like many other countries, has implemented a State of the Environment (SOE) Reporting program. Prepared for Canadians interested in their environment, SOE Reporting takes many forms: fact sheets, special reports, newsletters, environmental indicators, an environmental information network, ecological monitoring, and national overview reports.

These products are the result of an increasingly strong partnership involving federal, provincial and territorial governments, private industry, academia, non-governmental organizations, and individual Canadians. Because the environment is affected by decisions and activities undertaken at all levels of society, it is imperative that all of these stakeholders have access to timely and credible environmental information and assessment.

The SOE Report series is designed to provide Canadians with careful, objective analysis and interpretation of data which will identify significant conditions and trends in the environment. Of equal importance are the explanations for these trends and the actions being undertaken to sustain and enhance the natural environment.

The State of Canada's Climate: Temperature Change in Canada 1895-1991 is another report in the SOE series that is intended to provide the most recent available information about the nature of the Canadian climate and how it may be changing. It is hoped that this report will foster an increased awareness of the state of the natural environment, including the global climate system, and will thereby encourage environmentally responsible decision-making and management practices by all segments of society.

Specialists who wish more information about the original scientific studies on which this report is based should contact the Canadian Climate Centre, Atmospheric Environment Service, 4905 Dufferin Street, Downsview, Ontario, M3H 5T4.

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Summary

Changes in average annual temperature between 1895 and 1991 were analyzed for 131 stations across the country to determine both national and regional temperature trends.

Nationally, the country has warmed by a statistically significant 1.1°C over the period of study, although the warming has not been consistent throughout the entire time span. Three distinct phases are apparent in the national temperature record: a warming from the 1890s to the 1940s, a cooling from the 1940s to the 1970s, and a resumption of warming from the late 1970s on.

The 1980s were indisputably the warmest decade on record in Canada, with the 1940s in second place, and the 1930s in third. Five of the last twelve years (from 1980 to 1991) rank among the warmest twenty-five of the past century.

Regionally, temperature changes have varied from a moderate cooling of 0.6°C around Baffin and Ellesmere Islands to a substantial warming of 1.7°C in the Mackenzie District. With the exception of the Baffin and Ellesmere Island area, all regions of Canada have shown some degree of warming, although the trends have not been statistically significant in all areas. The warming shows most strongly in central Canada, in a broad band running from northwest to southeast through the Mackenzie District and the Prairie Provinces. It is less pronounced but still significant farther east in the Great Lakes Basin/St. Lawrence Lowlands and in the Shield country of Ontario and Quebec. It is weakest on the country's Atlantic and Pacific edges and in most areas of the Arctic.

The warming that has been observed in Canada over the past century is unquestionably real and significant, though its intensity has varied from decade to decade and from region to region. Canadian temperature trends are similar to those that have been observed globally, both in the general magnitude of warming and in the variability of the temperature patterns.

The increase in Canadian and world temperature averages is consistent with predictions of global warming as a result of an enhanced greenhouse effect. However, these increases are still within the limits of natural variability and cannot yet be attributed unequivocally to greater greenhouse warming.

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Introduction

Climatic change is influenced by both natural and human factors. As a natural process, it occurs on a variety of scales. It may be influenced by changes in the sun's radiation, volcanic activity, alterations of ecology or topography, or various other natural factors. Some of these have been sufficient to cause Canada's climate to shift from the ice age conditions that existed a mere 15 000 years ago to the temperate conditions that have prevailed for the past 10 000. Others bring about the modest fluctuations that make one year's weather different from another's.

Since the early 1970s, scientists around the world have become concerned that certain human activities, especially the burning of fossil fuels, have also become influential factors in the process of climatic change. It appears that these factors may now be causing unprecedented changes within the earth's climate system and may eventually raise average global surface temperatures to their highest levels in several hundred thousand years. Moreover, these changes may occur very rapidly, perhaps before the middle of the next century. Given the potential impact of such an event on the environment, many human societies and natural ecosystems could face serious problems of adaptation and survival.

Because temperature, rainfall, and other climatic elements can vary substantially from one year to another at a given location, it is often extremely difficult to distinguish an important emerging trend from a mere short-term irregularity in the climatic pattern. But in view of the danger of major climatic change, it is important that we have an early warning not only of the changes themselves but also of their nature and the rate at which they are occurring.

Under Canada's Green Plan, attempts are now being made to resolve some of the uncertainties surrounding climatic change and to improve our ability to recognize significant trends as they emerge. The knowledge gained from these studies will help Canadians shape their response to climatic change and will contribute as well to efforts to deal with the problem at a global level. Publications such as *The State of Canada's Climate: Temperature Change In Canada 1895-1991* will keep Canadians informed of the progress of this work.

The present report deals with a single but crucial climatic variable, temperature. It examines both the historical and geographical pattern of temperature variation in Canada during the past 100 years and indicates whether or not the changes observed represent a statistically significant trend. As well as reflecting the temperature changes that have occurred during this period, the data on which this report has been based provide a useful foundation for interpreting future changes.

The report is intended for a non-specialist audience. Readers who would like more background on Canadian climate and its processes should look at the very readable introduction by David W. Phillips, *The Climates of Canada* (Environment Canada, 1990). For a concise but authoritative summary of climatic change and related issues, consult *Understanding Atmospheric Change* by Henry Hengeveld (SOE Report No. 91-2).

Chapter 1

The Climate System

What is Climate?

The climate of a place may be defined as a "composite" of the long-term prevailing weather that occurs at that location. It is the normal weather pattern for that place, and we know that it will recur, with some small variations perhaps, from year to year. Our sense of a place's climate leads us to expect that temperatures at a particular time of year will fall within a certain range, that they are unlikely to rise above or fall below certain extreme values, that enough rain will fall at certain times of year to sustain the crops, and so on. Even the exceptions to these patterns often occur with some regularity. Thus, although rainfall may normally be reliable in a particular region, we may also know that it is unlikely that a ten-year period will go by without at least one serious drought.

It is this regularity that makes climate so important, because it creates the long-term conditions that allow ecosystems to evolve and survive. For human societies, this reliability is equally important for such basic activities as agriculture and settlement. When climates change, all species, including humans, must either adapt or migrate if they are to avoid major stress.

Ultimately, climate is a consequence of the way the atmosphere redistributes the sun's energy. Because the intensity of solar radiation changes with latitude, the tropics are heated much more intensely than the poles. It is this imbalance that drives the complex pattern of atmospheric and oceanic motions that redistribute heat and moisture from one part of the globe to another and cause our weather.

Local and regional climates are highly influenced by latitude, altitude, topography, and the proximity of large water bodies such as the oceans. Globally, climate is affected by complex interactions involving the sun, the land, the sea, the air, the earth's ice cover, and its plants and all other life forms. Although these interactions are still far from completely understood, we know much more about them than we did just a few years ago, and present scientific research is enhancing our knowledge further.

Measuring Climate

Climate is usually described in terms of the familiar elements of the weather. Temperature and precipitation are the essential indicators, but others such as sunshine, wind, cloud cover, atmospheric pressure, humidity, and evaporation can be added to provide a fuller and more complete picture. When these elements are measured systematically at a site over a period of several years, we eventually accumulate an archive of observations from which we can construct an accurate summary of that place's climate. Using a variety of statistical techniques, we can compute averages and ranges for different climate elements as well as measures of variability and frequency of occurrence.

Because climate is variable, a single locality's climate record may show different climates for different periods of time. This is particularly likely where the climate record is long and substantial changes, such as urban growth, have greatly altered local conditions. How then do we decide which of these climates is the normal climate for that place? The standard practice is to base the calculations on the last three complete decades. The resulting summaries are referred to as the climate "normals," and they are updated at the beginning of every new decade. The climate record since 1941, for example, is covered by three sets of normals: 1941-1970, 1951-1980, and 1961-1990.

The use of standard climate normals makes it much easier to compare climate data from different locations. As long as the base values, length of record, and method of computation are compatible, reliable comparisons can be made between various parts of a country or between different parts of the world. To facilitate such comparisons, the World Meteorological Organization (WMO), an agency of the United Nations, has issued guidelines and regulations for recording and processing climate data. These have greatly benefited international climatological studies, and have been essential to current international efforts to study global climatic change.

Like any other statistical measure, climate summaries are only as good as the data on which they are based. For the past 150 years or so, regular programs of observation

using reliable instruments under controlled conditions have produced a large body of relatively high quality data for many locations around the world. Nevertheless, changes in instruments, sites, and procedures, alterations in local conditions, and incomplete observations can all introduce errors which may give a false reading of climatic change. Careful processing of the data, however, can minimize the effects of such distortions.

In Canada, Toronto City has the longest continuous climate record of any station in the country. Observations began at Fort York in January 1840 and have continued within a few kilometres of the original site without interruption to the present day. Most other stations in Canada began operations much later, but a number of stations have records extending back into the late 1800s.

At present, there are some 2200 climate stations across Canada, which provide twice daily readings of temperature and precipitation. More detailed information for weather forecasting purposes comes from another 500 principal and automatic stations. All of this information is checked for consistency and accuracy and submitted to the Canadian Climate Centre in Downsview, Ontario, where it is summarized and used in climatic analyses, then archived for future reference. The Centre's archives now contain nearly three billion climate observations, covering approximately 8600 locations.

Temperature

Temperature is arguably the most significant of all climatic variables. It has the most immediate effect on human comfort, it plays an important part in determining the composition of ecosystems, and is strongly related to other atmospheric processes such as evaporation, precipitation and the movement and characteristics of air masses.

One of the more striking features of the Canadian climate is the very wide range of temperatures that has been recorded in the country. These extend from an extreme low of -63°C (at Snag, Yukon, on February 3, 1947) to an all-time high of +45°C (at Midale and Yellow Grass, Saskatchewan, on July 5, 1937). In any given year, the Canadian climate record is likely to show temperatures at least as low as -50°C in winter and as high as +35°C or +40°C in summer somewhere in the country.

Even individual locations often show quite astonishing differences between extreme summer and winter temperatures. The most impressive contrasts are found on the southern Prairies. At Regina, for example, temperatures have dropped as low as -50°C and soared as high as +43°C. Elsewhere in the country, the differences are not as spectacular. Nevertheless, temperatures in the more populous inland areas of Canada usually cover a wider spectrum than those for similar latitudes in Europe and Asia.

Average annual temperatures provide the simplest measure of the overall warmth of a locality's climate. These too show considerable diversity from one part of the country to another, varying from about 2° to 10°C across the south to about -15° to -20°C in the far north. Typical east coast values run from 2° to 7°C, while along the west coast they are considerably warmer at about 7° to 10°C (Figure 1a).

Seasonally this variability is even more pronounced. Winter averages, throughout the continental interior, vary from about -5° to -20°C in the south to about -30° to -35°C in the far north. Along the east coast values typically range from about -2° to -10°C, while along the west coast they are much warmer at about 0° to 5°C (Figure 1b). Summer averages are typically 17° to 22°C in the south and 2° to 7°C in the far north. In the Maritimes they are about 15° to 20°C, while on the west coast they are slightly cooler at about 12° to 17°C (Figure 1c).

Such diversity is partly explained by the enormous size of the Canadian land mass. More than 40° of latitude lie between the country's southern and northern extremities - almost half the distance between the equator and the North Pole - and latitude, with its direct effect on the intensity and duration of sunshine, has a substantial influence on climate.

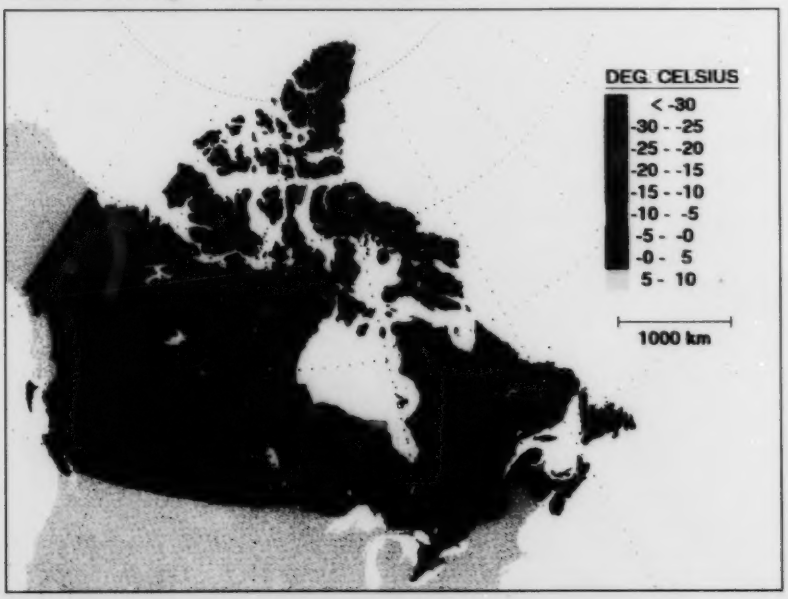
But other factors are important as well. One of these is topography. As Figure 2 shows, Canada can be divided into six distinct landform regions - the Western Mountains, the Great Plains, the Canadian Shield, the Great Lakes Basin/Lower St. Lawrence River Lowlands, the Appalachian Highlands, and the Arctic Archipelago. These features can have a considerable effect on the movement of large air masses. Regina's temperature extremes, for example, owe much to the influence of the massive ranges of the Western Mountains. These impede the normal westerly flow of mild air from the Pacific, leaving the Prairies open to frequent incursions of polar air from the Arctic and tropical air from the American southwest or the Gulf of Mexico.

Large bodies of water such as the oceans or the Great Lakes also have an important effect on climate, moderating temperature extremes and providing moisture for coastal localities and sometimes for those downwind as well.

Figure 1(a)
Annual Average Temperature 1951-80

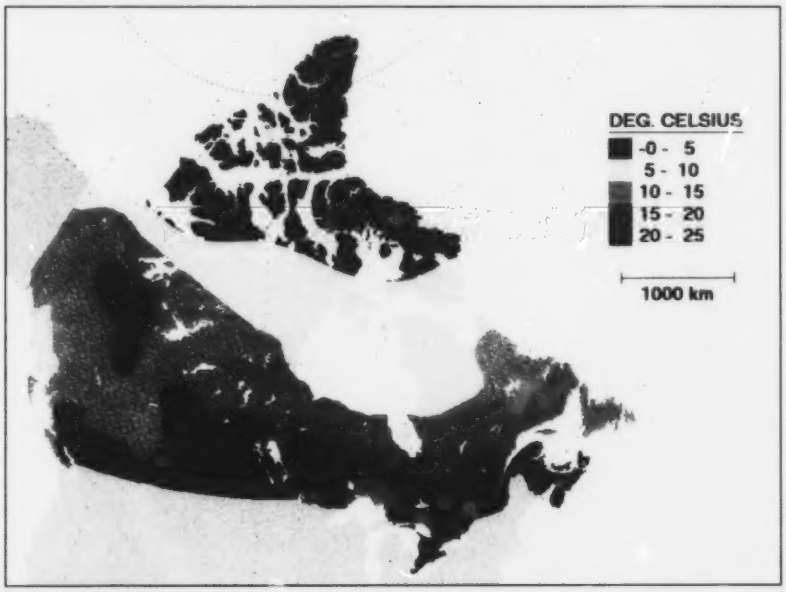
SOURCE: Environment Canada.

Figure 1(b)
Winter Average Temperature 1951-80



SOURCE: Environment Canada.

Figure 1(c)
Summer Average Temperature 1951-80



SOURCE: Environment Canada.

Figure 2
Major Relief Features

SOURCE: Environment Canada.

Vancouver, for example, owes its enviable climate largely to the proximity of the Pacific, which cools the prevailing westerlies in the summer and warms them in the winter. With an average annual temperature of 10°C, Vancouver has never experienced temperatures lower than -18°C nor higher than 33°C in more than 90 years of record.

Altitude, the exposure and orientation of the site, land slope, and a variety of other factors can further influence local climate conditions. It is the interaction of all of these with the large-scale circulation patterns of the atmosphere that creates the regional diversity of Canada's climate. Canada can, in fact, be divided into several different climatic regions, the exact number depending on how broadly or narrowly we define our criteria. For this report, we have identified 11 such regions. These are shown in Figure 3. Each has a unique pattern of climate and each is likely to respond to larger-scale climatic changes in a distinctive way.

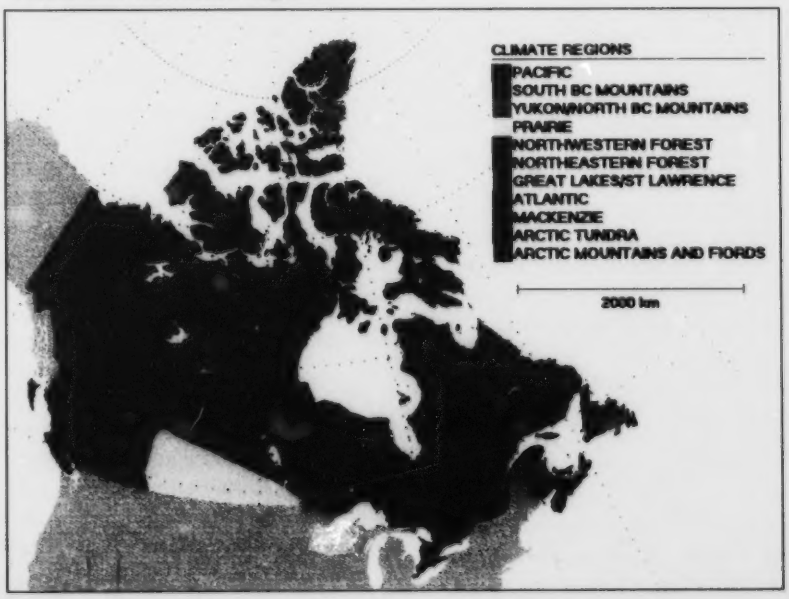
Temperature Past and Present

Historically, Canada has experienced both warmer and colder climates than it has now. Since the end of the last ice age some 10 000 years ago, the earth's average temperature has been relatively stable, varying within a range of only 1.5° to 2.0°C. Even such a small variation can have significant environmental effects, however, especially on a regional scale where temperature changes may exceed the global average.

Two notable warming episodes have occurred since the end of the last ice age. The first peaked about 6 000 years ago, when the average global temperature was probably about 1°C warmer than it was at the beginning of the twentieth century. In Canada, the warming was particularly pronounced in the far north, where summer temperatures are estimated to have been at least 3°C higher than at present. In the south, the warming was less intense, with average temperatures about 1°C higher than present values.

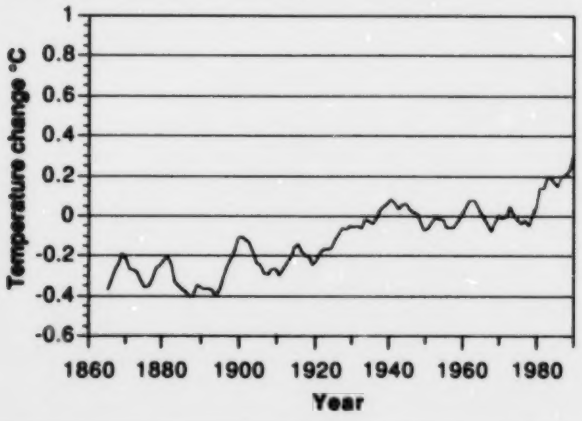
The second warming episode occurred between about 950 AD and 1250 AD, with average temperatures in the Northern Hemisphere about 0.5°C higher than early twentieth-century values. The effects of this warming were particularly significant in the higher latitudes, where the sea ice cover was much diminished and the tree line was much farther north. During the fifteenth century, a significant cooling began, with temperatures dropping to as much as 0.5°C below present values and lasting for the next few hundred years.

Figure 3
Canadian Climate Regions



SOURCE: Environment Canada.

Figure 4
Departures of Annual Average Global Surface Temperatures, 1860-1989, From the 1950-79 Average



SOURCE: Adapted from Boden et al. 1990, Hengeveld 1991.

Since the 1890s, global temperatures have shown a sharp upward trend that has generally persisted to the present day (Figure 4). Although a gradual cooling is evident after the mid-1940s, temperatures began to rise again during the late 1970s and are now close to the values that prevailed during the warm period of the Middle Ages. Should these warmer temperatures continue, we can expect to see a return of the sea ice and vegetation patterns of this Medieval warm period.

What Causes Temperature Change?

The temperature at the earth's surface is influenced by a number of factors, including the amount of energy received from the sun, the amount of solar energy reflected back to space by the earth's surface and atmosphere, and the amount of heat kept within the atmosphere by heat-retaining "greenhouse" gases, such as carbon dioxide and methane.

Large-scale temperature changes such as those that brought about the earth's ice ages appear to be at least partly related to long-term changes in incoming solar energy resulting from periodic variations in the earth's orbit and the tilt of its axis. Changes in the concentration of important greenhouse gases also appear to have played an important role. Scientific studies have shown a very close relationship during the past 160 000 years between global temperature changes and atmospheric concentrations of these gases. Indeed, it is this relationship that underlies much of the present concern about the future effect of rising concentrations of these gases on the world's climate.

Explanations for the less dramatic fluctuations of the past 10 000 years are more elusive. Since greenhouse gas concentrations during this period did not alter appreciably until very recently, they do not appear to have had a significant influence on these changes. Small variations in the energy output of the sun, however, may have had some effect, although how much is not yet clear.

On a relatively short time scale, volcanic eruptions may affect the variability of climate by injecting huge volumes of dust and microscopic particles into the stratosphere. These deflect some of the incoming sunlight and have a temporary cooling effect. Generally, the effect lasts for little more than a year, although the impact of a very large eruption, such as that of Mt. Pinatubo in 1991, may last for two or three years.

Changes in ocean currents or sea surface temperatures can also have a noticeable effect on climatic conditions. The best known of these is the El Niño phenomenon, which is marked by a pronounced warming of surface waters in the eastern and central portions of the tropical Pacific. El Niños occur every three to ten years and coincide with a large shift in atmospheric pressure from one side of the Pacific to the other. By transferring enormous amounts of heat to the atmosphere, they disrupt normal global circulation patterns and significantly alter regional climatic conditions, changing rainfall patterns and making some areas hotter while others become cooler. El Niños are often associated with warm years in the global climate record. An opposite phenomenon, involving a cooling of the equatorial Pacific, is known as La Niña, and is associated with cooler years globally.

Usually about 18 to 24 months pass between the onset of an El Niño and the return of normal conditions in the Pacific. In recent years, major El Niño episodes have occurred in 1957, 1965, 1972/73, 1982/83, 1987/88, and 1991/92.

In Canada, El Niños tend to most significantly affect our weather for a short period between December and March, when they commonly produce milder than usual winters on the Prairies, as in the recent winter of 1991-92. Farther east, the effects are more variable, and both warming and cooling episodes here can be linked to the El Niño.

The temperature record in many localities has also been significantly affected by urban growth. Cities are both producers and absorbers of heat, and consequently average temperatures in many areas have risen as observation sites have been affected by increasingly dense urban development. Over the past 100-year period, city temperatures have been influenced by both natural climatic changes and the effects of urbanization. When attempting to measure the natural changes, climatologists must estimate and filter out the urban influence by the use of statistical methods.

The temperature changes that we see over a particular period of time are the net result of these and a number of other interacting factors, some of which tend to increase temperature and some of which tend to decrease it. Given the present state of our knowledge, we cannot say with certainty which factors are having the most decisive effect on recent temperature patterns. However, by building up an increasingly accurate and detailed picture of recent temperature changes, we shall eventually be in a better position to link cause and effect and solve the puzzle of climatic change.

Future Temperature Change

Industry, transportation, agriculture, and deforestation have all contributed to the buildup of greenhouse gases in the atmosphere. During the past 200 years these activities have caused greenhouse gas concentrations to rise well above the highest natural levels of the last 160 000 years.

Recently, the Intergovernmental Panel on Climate Change, a group of leading atmospheric scientists convened by the World Meteorological Organization and the United Nations Environment Programme, concluded that the average world temperature would increase 1°C above the present value by 2025 and 3°C before the end of the next century, if concentrations of these gases continue to rise at the present rate. With a 1°C rise, global temperatures would equal the highest values of the postglacial period. A further rise would result in temperatures that the world has not experienced for at least the last 160 000 years.

For a number of reasons, actual temperature changes over the next few decades could turn out to be significantly less - or significantly more - than predicted. Given the potentially serious consequences of such changes, however, it is important that we pay very careful attention to how the earth's climate is evolving.

Chapter 2

Regional Temperature Changes

Measuring Temperature Change

Measuring climatic changes across an area as large as Canada depends on the availability of long and complete runs of instrumental observations for every major region of the country. Although continuous observations for some more northerly locations date back only to the mid-1940s or later, this information has been available for most of the country since about 1895. Consequently, that year was chosen as the starting date for this study.

To compile a set of data that would best reflect both national and regional temperature variations, 131 strategic locations were identified across the country. These were selected not only for the quality and completeness of their data, but also for the degree to which their climates were consistent with broader regional patterns. For each of these locations, monthly average temperatures were compiled from the daily record of maximum and minimum temperatures. These averages were compared with data from nearby locations to filter out peculiarities related to the station's geography and make the data more representative of the surrounding area. The adjusted data were then combined to produce a set of averages for each of the 11 climatic regions as well as a set of national averages.

Regional Trends

To measure the amount of temperature change in each region, average temperatures for each year were compared with the regional average for 1951-1980, and the differences (or "departures") plotted on a graph. Using departures rather than actual temperatures makes it possible to relate all of the regional data to the same reference point, in this case, the regional normals for 1951-1980. This technique greatly reduces the effect of local influences on a single dataset and allows records of differing lengths to be combined into regional indices.

The amount of temperature change for the entire period has been calculated and is indicated by a straight line on each graph – the steeper the line, the greater the amount of change. Mathematical tests have also been applied to determine whether the amount of change was statistically significant.

For a temperature trend to be significant in a statistical sense, it must be above a certain level of variability. It also must not be attributable to some technical cause such as shortness of the data record. It will be evident then, that the threshold of significance can change from one place to another. While a warming of, say 0.8°C may be significant for one region of the country, for a particular period of time, it may not be for another, where the variability or the period may be different.

In the following regional summaries, a descriptive overview of climatic influences and present climate conditions is included for each region. The statistical significance is computed for each trend-line, as an indication of whether the trend is significantly different from 0°C, when taking into account the variability characteristics of the data.

The Pacific Coast

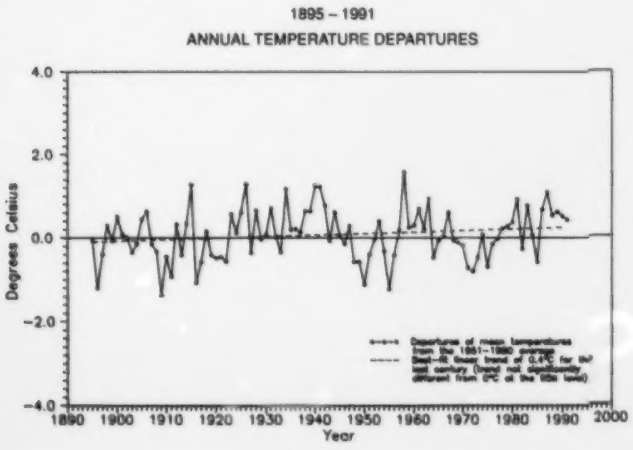
Extending along a narrow coastal strip from Vancouver Island and the lower mainland in the south to the Queen Charlotte Islands in the north, the region consists of islands, west-facing slopes, uplands, and indented fiords.

Dominated by the onshore flow of Pacific air, the climate is moist and mild. During the winter months, frequent Pacific storms produce abundant precipitation as they encounter the rising mountain slopes. In summer, large high pressure areas off the coast produce prolonged spells of fine weather.

Annual temperatures average about 8°C at Prince Rupert on the north coast to about 10°C at Vancouver and Victoria. In winter, temperatures average above freezing; in summer, they rarely rise above 30°C.

As Figure 5 shows, the Pacific Coast has experienced a slight warming trend over the last century, with an overall temperature increase of 0.4°C. This trend, however, is not statistically significant.

Figure 5
Pacific Coast Temperature Trend



SOURCE: Environment Canada.

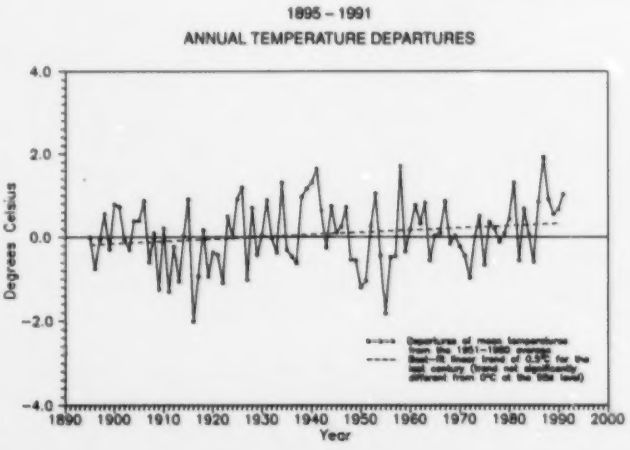
The South British Columbia Mountains

Bounded by the Coast Mountains to the west, the North British Columbia Mountains Region to the north, and the Rocky Mountains to the east, the region comprises broad plateaus, valleys, highlands, and mountains. The climate is typically continental, with low precipitation and marked extremes of temperature. A variety of sub-climates, including some of the driest in Canada, are also present. The most arid areas are located in the valley bottoms and on the east-facing slopes in the rain shadow of the Coast Mountains.

Annual temperatures average about 3°C at Prince George in the north and about 8°C at Kamloops in the south- central interior. In general, winters are cold, dominated by Arctic air flowing down from the north or pushing westward from the Prairies through the many Rocky Mountain passes. Numerous Pacific disturbances bring cloud and snow. Summers are warm and quite dry with frequent hot days, especially in the central interior. Average July temperatures decrease from south to north, exceeding about 20°C in the south and falling just under 15°C in the north.

The region shows a similar warming pattern to that of the adjacent Pacific Coast. Figure 6 indicates a warming over the last century of 0.5°C. This trend is also not statistically significant.

Figure 6
South BC Mountains Temperature Trend



SOURCE: Environment Canada.

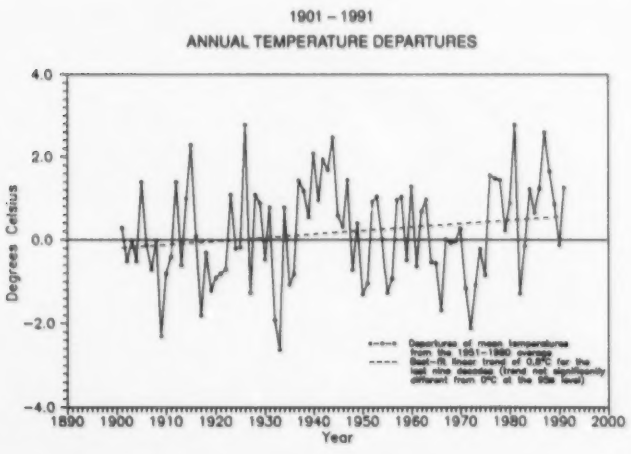
The Yukon/North British Columbia Mountains

This region includes all of Yukon Territory and British Columbia north of about the 56th parallel. The terrain is highly variable, ranging from alpine to sub-alpine to lowland boreal.

Annual temperatures average about 0°C in the south and about -10°C in the north where permafrost is widespread and continuous. Summers are short and cool, winters long and very cold. Precipitation is light to moderate, varying from about 200 mm annually at Whitehorse to well over 700 mm along the coastal fiords.

The temperature trend here, as shown in Figure 7, is similar to that along the Pacific Coast and in southern B.C., although the amount of warming over the last 90 years is somewhat greater at 0.8°C. The trend here, as in the two previous regions, is also not statistically significant.

Figure 7
Yukon/North BC Mountains Temperature Trend



SOURCE: Environment Canada.

The Prairies

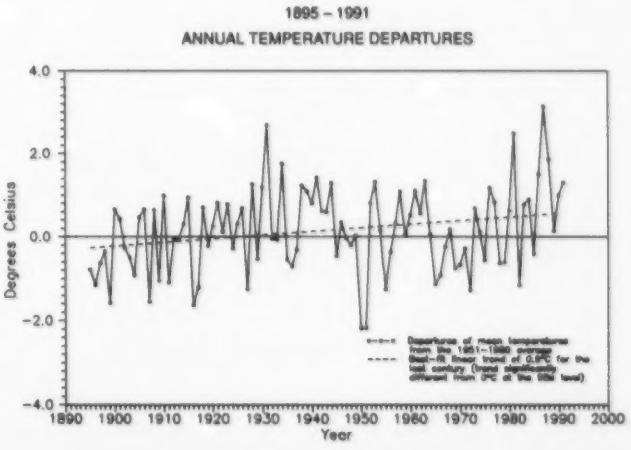
The region extends eastward from the foothills of the Rocky Mountains across the southern portions of Alberta, Saskatchewan, and Manitoba. Although there are no major relief features, there is a gradual downward slope of the land from west to east.

The western mountain ranges frequently block the flow of Pacific air into the region, leaving it exposed to air masses from the Arctic and the southern United States. When Pacific air does enter the Prairies, it has lost much of its moisture as a result of its passage across the mountains. Consequently, the region's climate is dry and prone to extremes of temperature.

Annual temperatures average about 3°C to 4°C in western Alberta, about 1°C to 2°C in Saskatchewan, and about 3°C in southern Manitoba. Summer to winter temperature differences are greater here than in any other region of the country. Winter temperatures generally decrease from southwest to northeast, while summer averages decrease from south to north.

Figure 8 shows a gradual warming between the 1890s and the 1940s, a cooling between the 1940s and 1970s, and a resumption of warming from the 1970s into the 1990s. Overall the temperature change for the region is a statistically significant 0.9°C over the last century.

Figure 8
Prairies Temperature Trend



SOURCE: Environment Canada.

The Northwestern Forest

The Northwestern Forest extends from the northern boundary of the Prairies north to the Mackenzie District at about the 60th parallel and from the foothills of the Rocky Mountains east to the Manitoba/Ontario border. The landscape, like that of the Prairies, is low and without prominent relief features.

The area comes generally under the influence of the cold, dry Arctic air mass. Pacific air, when it arrives, is milder but has lost most of its moisture as a result of its passage over the mountains.

Annual temperature averages range from about 2°C at Prince Albert, Saskatchewan, in the south to about -1°C at Fort Nelson, British Columbia, in the northwest. Summers tend to be short and cool, while winters are long and very cold with persistent snow cover. Annual precipitation is light, averaging about 450 mm across the region, with more precipitation falling in the summer than in the winter in most localities.

As Figure 9 shows, the pattern of temperature variation over the last century for the region is very similar to that for the Prairies (Figure 8) and the Mackenzie District (Figure 13). Overall, a statistically significant warming over the last century of 1.3°C, the second highest of all the regions, is shown.

The Northeastern Forest

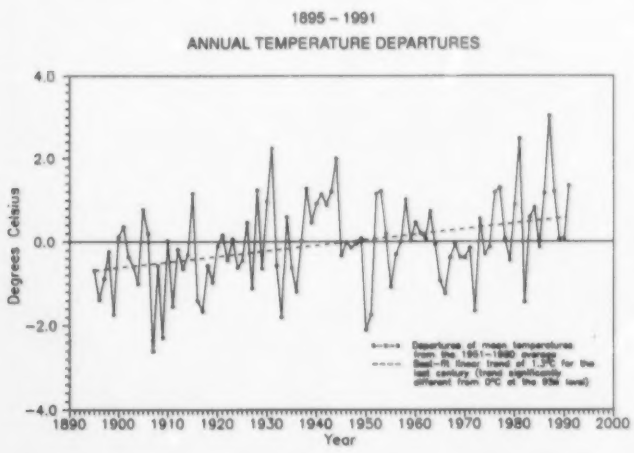
The Northeastern Forest lies between about 46°N and the tree line at about 57°N and extends from approximately the Ontario/Manitoba border to the Atlantic coast of Labrador including the Lower Saint-Lawrence and the Gaspé Peninsula. The region takes in much of the Canadian Shield as well as the Hudson Bay Lowlands.

Exposed to storm systems moving northeast out of the Ohio Valley/Great Lakes area as well as to air masses crossing Hudson Bay, the Northeastern Forest is more humid than its western counterpart. However, the transition between them is not precise, and the boundary between these regions is somewhat arbitrary.

Summers are cool, and winters are long, cold, and snowy. Annual precipitation is about 400 mm at Churchill, Manitoba, and increases to the south and east, averaging more than 1000 mm at Sept-Iles, Quebec. Annual temperatures average about -7°C at Churchill in the northwest, close to the tree line; about -4°C at Schefferville, Quebec, in the northeast; and about 1°C at Sept-Iles near the mouth of the St. Lawrence.

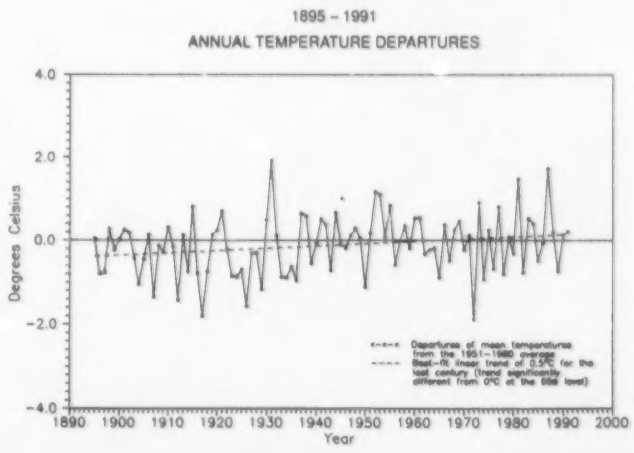
Figure 10 shows a moderate but nevertheless statistically significant regional warming of 0.5°C for the Northeastern Forest over the course of the century.

Figure 9
Northwestern Forest Temperature Trend



SOURCE: Environment Canada.

Figure 10
Northeastern Forest Temperature Trend



SOURCE: Environment Canada.

The Great Lakes Basin/St. Lawrence Lowlands

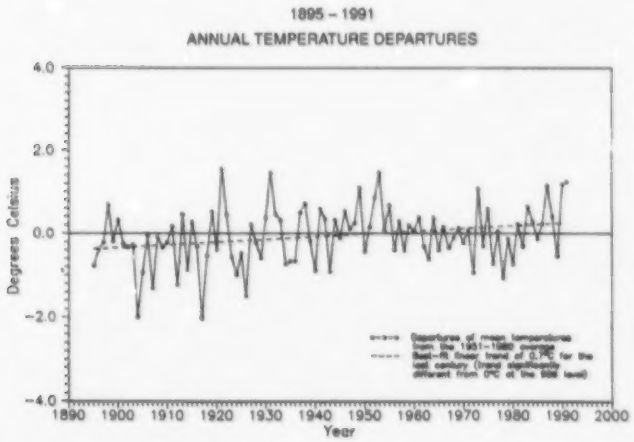
The region takes in southern Ontario and the extreme southern portion of Quebec, from Lake Huron in the southwest to Québec City in the northeast.

The climate is influenced by a diverse assortment of air masses from the Pacific, the Arctic, the Gulf of Mexico, and occasionally the Atlantic. The Great Lakes have a moderating effect on the temperature of the surrounding area and affect precipitation downwind. The result is a variable climate with marked temperature extremes and no extended wet or dry spells.

Annual temperatures average about 8°C in the southwest, about 6°C in the Ottawa River Valley, and about 5°C at Québec City. Daily temperatures average above freezing from March to November. Annual precipitation averages about 800 to 1000 mm in the southwest, depending on elevation and proximity to the lakes, and generally increases to about 1100 mm at Québec City.

The Great Lakes Basin/St. Lawrence Lowlands show a statistically significant warming of 0.7°C over the last century (Figure 11), just slightly greater than in the adjacent Northeastern Forest.

Figure 11
Great Lakes Basin/St. Lawrence Lowlands Temperature Trend



SOURCE: Environment Canada.

Atlantic Canada

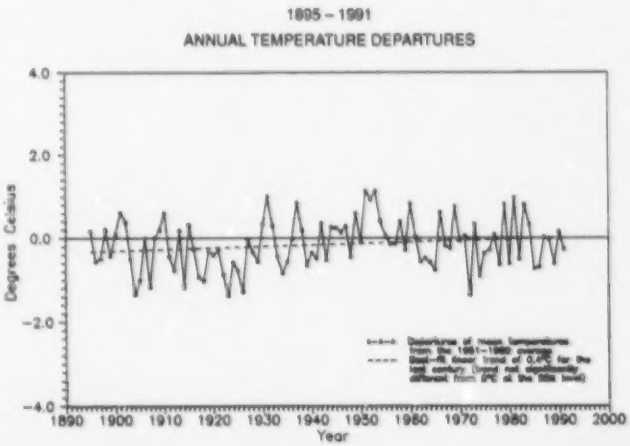
The region includes the provinces of New Brunswick, Nova Scotia, Prince Edward Island, and Newfoundland.

Because of the prevailing westerly air flow, the climate is essentially continental, despite its maritime location, and shows wide daily and seasonal temperature fluctuations that are not found in a true maritime climate. However, the ocean does have a number of important effects on local conditions. Coastal locations in Newfoundland and Nova Scotia are cooled in summer by the cold waters of the Labrador Current. Winter pack ice along the coasts often delays the arrival of spring, while in autumn the relatively warm waters of the Gulf of St. Lawrence can retard the onset of winter by a few weeks.

Precipitation is plentiful throughout the region, ranging from about 1000 mm per year in northern New Brunswick to more than 1500 mm along the Atlantic shores of Newfoundland. Annual temperatures average about 6°C in New Brunswick and Prince Edward Island, about 7°C in central coastal Nova Scotia, and about 5°C along the Atlantic shores of Newfoundland.

Figure 12 shows a warming for the region of only 0.4°C over the last century. This is less than in most other areas of the country, though similar in magnitude to the Pacific coast. As in the case of the Pacific coast, the trend here is not statistically significant.

Figure 12
Atlantic Canada Temperature Trend



SOURCE: Environment Canada.

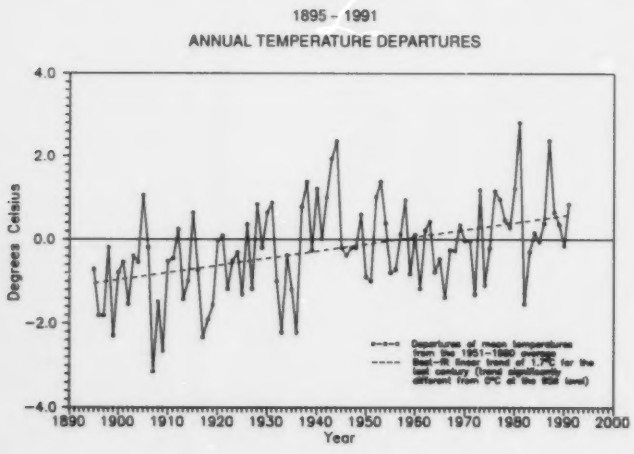
The Mackenzie District

The region takes in a major portion of the Mackenzie River drainage basin, including Great Bear and Great Slave lakes. The terrain is relatively flat, rising gently from the east to the Mackenzie Mountains in the west. In the winter, the area is dominated by the Arctic air mass. Incursions of Pacific air are common in summer.

Summers are cool and winters are very cold. Annual temperatures average about -6°C at Yellowknife in the south and about -9°C at Inuvik in the north. Annual precipitation is about 250 to 350 mm, with most occurring in late summer and early fall.

The Mackenzie District shows the greatest overall warming in the country, a substantial 1.7°C over the last century (Figure 13). This trend is statistically significant and is part of a larger area of warming extending into the adjacent Northwestern Forest and Prairie regions.

Figure 13
Mackenzie District Temperature Trend



SOURCE: Environment Canada.

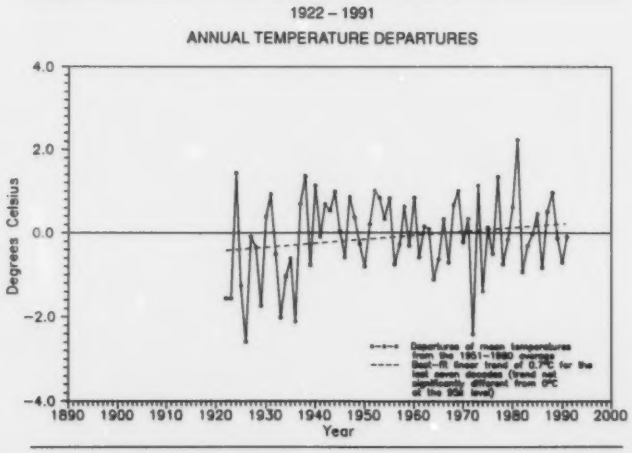
The Arctic Tundra

Treeless, open, and covered with ice caps and permafrost, the Arctic Tundra includes most of Canada north of the tree line (excludes Arctic Mountains and Fiords Region). Although the Arctic Ocean borders the northern shores of the mainland and surrounds the Arctic islands, it is frozen for much of the year and has little moderating effect. The absence of sunlight during the long winter months allows continuous cooling of the land and sea surface. When sunlight and warmer air return in the spring, their effect is abated by the high reflectivity of the snow cover. The eventual melting of the snow allows surface heating to resume, bringing on a brief period of intense ecosystem activity in high summer.

The Arctic Tundra can be divided into low, mid, and high Arctic environments, as one moves from the tree line towards the pole. Temperatures average above 0°C for most of July and August in the low Arctic but only in July in the mid and high Arctic. In all areas, winters are extremely cold, with daily temperatures averaging well below -30°C. Annual temperatures average about -10°C at Baker Lake in the south mainland and about -17°C at Resolute in the north Arctic islands. Precipitation is generally light throughout, with annual averages about 100 mm at Mould Bay in the west and about 135 mm at Resolute.

Because of the shorter period of record, temperature trends for the region are harder to assess. Figure 14 shows an overall warming of 0.7°C for 1922-1991, although a cooling trend is apparent from the 1940s on. These results, however, are not statistically significant.

Figure 14
Arctic Tundra Temperature Trend



SOURCE: Environment Canada.

The Arctic Mountains and Fiords

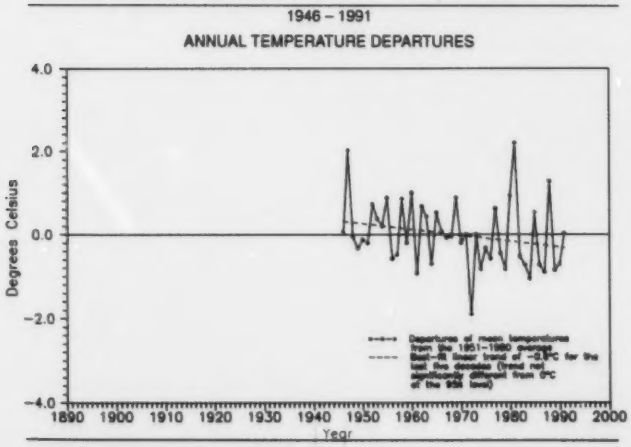
The region consists of a long, slender band of rugged, mountainous, and icy terrain along the eastern flanks of Ellesmere Island and Baffin Island and along the western shore of Baffin Bay and Davis Strait. This topography gives the region a distinctive climatic identity. Temperature is affected by elevation and the proximity of Baffin Bay and Davis Strait, while the mountains increase precipitation on the eastern side (because of the prevailing easterly circulation) and diminish it to the west.

Latitude is also important. Annual temperatures are higher in the south due to the proximity of Baffin Bay and Davis Strait. At Iqaluit in the southern part of Baffin Island, for example, the average value is -9°C, while at Clyde, farther north, it is -12°C. Annual precipitation averages are also higher in the south, with amounts of about 430 mm at Iqaluit and about 205 mm at Clyde.

Locations farther north are much colder and drier than similar tundra locations, with annual temperatures on Ellesmere Island averaging about -20°C at Eureka and about -18°C at Alert, Canada's northernmost settlement. Annual precipitation amounts average a mere 65 mm at Eureka and only about 155 mm at Alert.

The Arctic Mountains and Fiords have the shortest period of record in all of Canada, and consequently trends cannot be measured as reliably here as in the rest of the country. Overall, Figure 15 shows a cooling of 0.6°C over the four and a half decades from 1946 to 1991. However, this trend is not statistically significant.

Figure 15
Arctic Mountains and Fiords Temperature Trend



SOURCE: Environment Canada.

The Pattern of Regional Change

With the exception of the Arctic Mountains and Fiords, all regions have shown some degree of warming over the century, although the trends are not statistically significant in every case. Generally, temperature changes have followed a three-phase pattern, marked by warming from the late 1890s to the 1940s, followed by cooling into the 1970s, and a resumption of significant warming through the 1980s.

The warming shows most strongly in central Canada, in a broad band running from northwest to southeast through the Mackenzie District, the Northwestern Forest, and the Prairies. It is less pronounced but still significant farther east in the Great Lakes Basin/St. Lawrence Lowlands and the Northeastern Forest, and it is weakest on the country's Atlantic and Pacific edges and in most areas of the Arctic where longer records of data are available.

Chapter 3

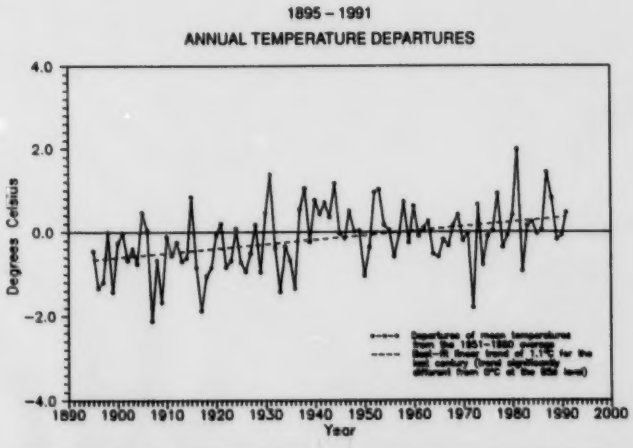
National Temperature Changes

A graph of mean annual temperature departures from 1895 to 1991 is shown for Canada as a whole in Figure 16. This graph is derived from the same data used to compile the regional graphs, although some adjustments were necessary to accommodate the shorter period of record of the Arctic stations and the greater spatial separation between them. Overall, Figure 16 indicates a statistically significant warming of 1.1°C for the period and shows the same progression from warming to cooling to renewed warming seen in many of the regions.

Warmest Years and Decades

The twenty-five warmest years of the twentieth century, based on annual mean temperature departures, are ranked from warmest to coolest in Table 1, as are the century's nine completed decades. Canada's warmest year (up to the end of 1991) was 1981, a year which was abnormally warm in almost every part of the country. The runner-up was 1987, which was unusually warm in most of southern Canada but not in the far north or along the extreme east coast. The third warmest year was 1931.

Figure 16
Canadian National Temperature Trend



SOURCE: Environment Canada.

Interestingly enough, such years as 1936, which saw maximum daily temperature records shatter across Manitoba and Ontario, and 1937, which recorded Canada's all-time highest temperature of +45°C, do not figure prominently in this list. While 1937 stands 16th among Canada's warm years, 1936 does not appear on the list at all. This serves to remind us that temperature abnormalities often do not occur consistently across the country. Hot weather in one part of

Table 1
Canada's National Temperature Summary

Canada's Warmest Years and Decades

Rank	Year	Decade
1	**1981**	**1980-89**
2	**1987**	1940-49
3	1931	1930-39
4	1944	1950-59
5	1938	1960-69
6	1953	1920-29
7	1952	1970-79
8	1977	1900-09
9	1915	1910-19
10	**1988**	
11	1940	
12	1958	
13	1942	
14	1973	
15	1960	
16	1937	
17	1947	
18	1905	
19	**1991**	
20	1930	
21	1941	
22	**1980**	
23	1969	
24	1943	
25	1963	

SOURCE: Environment Canada.

the country is often balanced by cool weather somewhere else. And within a region, the effect on the annual average of even the most searing heat waves may be diminished by greater cooling in other seasons.

Decadally, the 1980s are unquestionably the warmest decade of the century for Canada, with the 1940s ranking second, and the 1930s third. Five of the past twelve years (shown in bold type in Table 1) are in the warmest twenty-five, while three are in the warmest fifteen. This trend has continued into the early 1990s, with 1991 being the nineteenth-warmest year on record (although 1990 is well down the list in forty-sixth place, primarily because of regional differences in the warming patterns).

National Temperature Changes by Decade

The variability of warming patterns from region to region and from decade to decade can be seen clearly in the following series of maps. These show temperature departures from the 1951-1980 average for each of the nine decades since 1900. The analysis does not cover northern Canada until the 1950s, however, because of the absence of observation sites in the area before that time.

The first two decades of this century (Figures 17 and 18) show cooler than normal temperatures for those parts of the country, with the exception of southern British Columbia for the 1900 to 1909 period.

Figure 17
Average Annual Temperature Departures From 1951-80 Average For 1900 to 1909

SOURCE: Environment Canada.

Figure 18
Average Annual Temperature Departures From 1951-80 Average For 1910 to 1919

SOURCE: Environment Canada.

Figure 19
Average Annual Temperature Departures From 1951-80
Average For 1920 to 1929

SOURCE: Environment Canada.

The 1920s map (Figure 19) shows near normal to warmer than normal temperatures in much of western Canada, with a warmer than normal cell centred on the south-central Canadian Prairies. However, cooler than normal temperatures persisted in eastern Canada.

Figure 20
Average Annual Temperature Departures From 1951-80
Average For 1930 to 1939

SOURCE: Environment Canada.

In the 1930s (Figure 20), warmer than normal temperatures continued in the south central Canadian Prairies and southern and central British Colombia and spread eastward into southern Ontario. More northerly locations, however, were still below, or well below, normal.

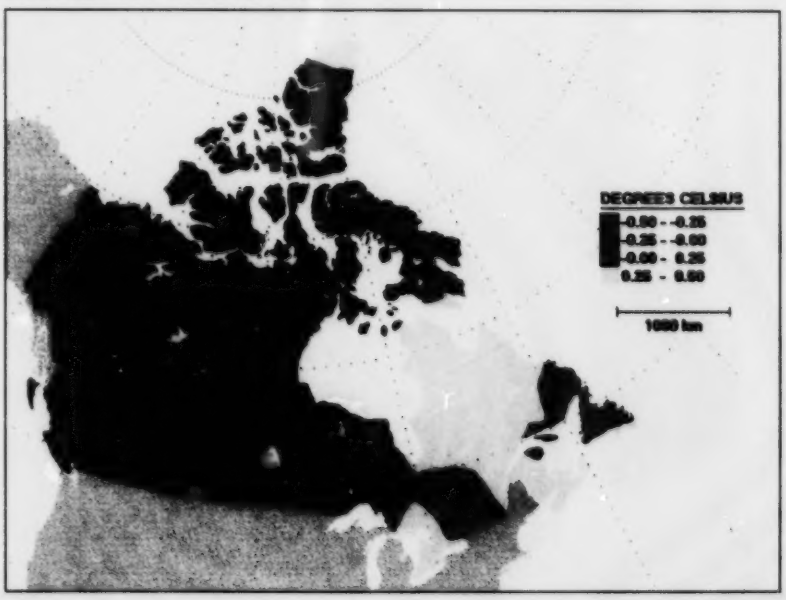
The 1940s, the second-warmest decade of the century, are characterized by continued and expanded warming in most regions (Figure 21), with the entire western half of the country experiencing well above normal temperatures. This warming was most pronounced in the northwest. Cooler than normal temperatures persisted in northern Quebec and Newfoundland.

Figure 21
Average Annual Temperature Departures From 1951-80 Average For 1940 to 1949

SOURCE: Environment Canada.

Data coverage for the entire Canadian land mass begins with the 1950s map (Figure 22). It shows a return to cooler than normal temperatures throughout most of western Canada. In some locations, specifically central British Columbia and the southern portions of Alberta and Saskatchewan, temperatures were well below normal. Throughout the entire eastern part of the country, however, temperatures were above normal, and even well above normal.

Figure 22
Average Annual Temperature Departures From 1951-80 Average For 1950 to 1959



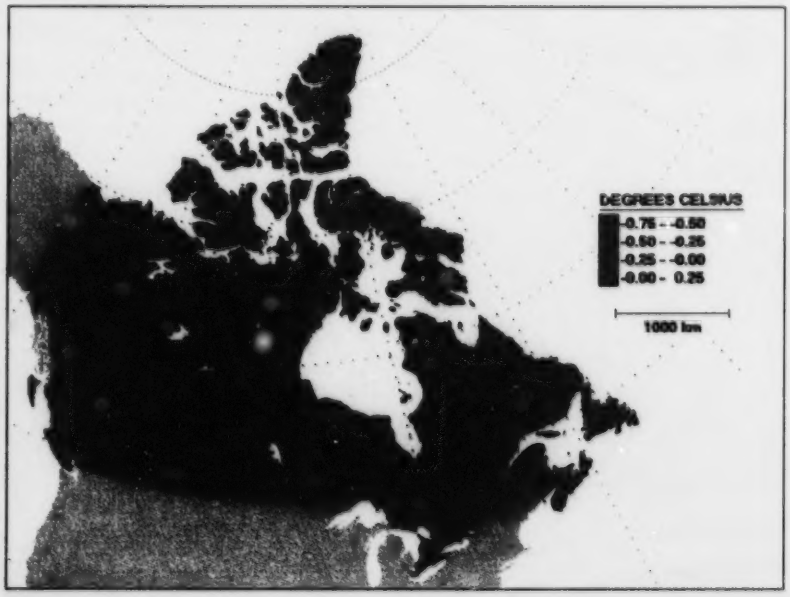
SOURCE: Environment Canada.

Figure 23
Average Annual Temperature Departures From 1951-80 Average For 1960 to 1969

SOURCE: Environment Canada.

The 1960s map (Figure 23) shows near normal conditions for most of Canada, with the exception of a well below normal cell centred on Great Slave Lake and two small well above normal cells located in western and southeastern British Columbia.

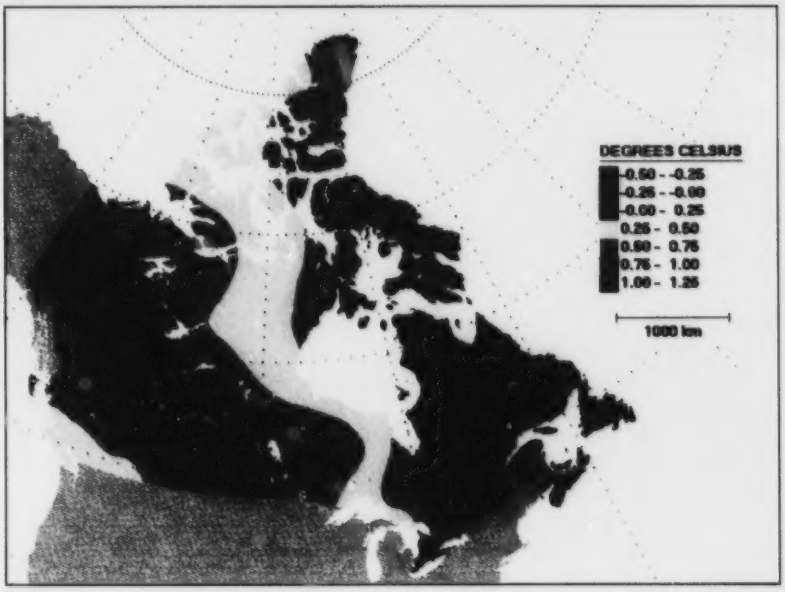
Figure 24
Average Annual Temperature Departures From 1951-80 Average For 1970 to 1979



SOURCE: Environment Canada.

Colder than normal conditions persisted throughout the 1970s for most areas of the country, with the exception of the Mackenzie River Basin (Figure 24). The decade saw well below normal temperatures throughout most of Quebec, Newfoundland and Labrador, and the eastern Arctic. The lower British Columbia mainland and most of Vancouver Island were also well below normal.

Figure 25
Average Annual Temperature Departures From 1951-80 Average For 1980 to 1989



SOURCE: Environment Canada.

The 1980s (Figure 25) experienced tremendous warming on almost a national scale, with a broad area of well above normal temperatures covering the entire central and western portions of the country. The central core of this warming, with values greater than 0.8°C above normal, extended from the Yukon in the northwest to southern Manitoba in the southeast. Only the extreme eastern area, consisting of the Atlantic Region, northern Quebec, and southern Baffin Island, showed below normal values. Similar annual temperature patterns have persisted into 1990 and 1991.

Conclusion

At least three conclusions can be drawn about temperature changes in Canada during the past century. First, the observed warming, 1.1°C nationally and as much as 1.7°C regionally, is unquestionably real and significant. It has been measured by reliable instruments under systematic conditions of observation; it is based on a large, relatively complete, and reasonably consistent body of data; and it has been calculated and verified by established and rigorous statistical procedures.

Second, this warming is part of a larger pattern of climatic change that has been observed in the world as a whole over a similar time span. According to recent studies, average land surface temperatures between 1881 and 1989 have risen by 0.53°C in the northern hemisphere and 0.52°C in the southern. The average global temperature change (combining both land and sea surface values) has been 0.50°C for the slightly shorter period 1890-1989.

Third, climatic change is non-uniform: it does not occur at the same rate or in the same way in every part of Canada. Instead, it shows large variations in both time and space. The variability from decade to decade that we see in Canada is apparent in other parts of the world too. The warming, cooling, warming sequence observed in most of the Canadian data, for example, is also characteristic of both the northern hemisphere and world trends (Figure 4).

The geographical variability of temperature change in Canada is typical of the broader world pattern as well. It was particularly apparent in the northern hemisphere in the 1980s. There, a sharp global temperature increase of 0.3°C for the decade was accompanied by average temperature rises of as much as 0.8°C in western Canada, yet over most of western Europe there was little or no change.

If temperature change is a global phenomenon - and the evidence clearly indicates that it is - why is there so much variation from one region to another? Recent research has confirmed a very strong connection between local climatic fluctuations and large-scale changes in the circulation of the atmosphere. These are related to changes in the intensity and position of major features like the jet streams and the large, quasi-permanent highs and lows that direct the flow of air around the world and exert a considerable influence on regional weather. It is these types of changes, for example, that cause the widespread and highly variable climatic disruptions that accompany the El Niño. Significant changes in regional circulation have been apparent in the 1980s.

As for the underlying causes of the general rise in temperature over the past century, we cannot at the present time draw any definitive conclusions. The changes that have occurred are still within the limits of the natural temperature variability of the last 1000 years, and we still do not know enough about the process of climatic change to isolate individual causal factors. However, these changes are consistent with predictions of warming resulting from a human-induced buildup of greenhouse gases - and, indeed, most of the world's leading atmospheric scientists see this as the most important single factor. Nevertheless, further monitoring and analysis of climatic conditions around the world will be necessary before we can finally determine the exact causes of the present rise in global temperatures.

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